REMARKS

Claims 1, 2, 4 and 6 through 9 are amended. Thus, claims 1 through 9 are presented for examination as amended.

Claims amendments have been made to eliminate element numbering and multiple dependencies. No new matter is added by the changes made herein.

Respectfully submitted,

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TITLE: METHOD FOR DETERMINATION OF A ZERO ERROR IN A CORIOLIS GYRO

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BACKGROUND

Field of the Invention

The present invention relates to Coriolis gyros. More particularly, this invention pertains ~~The invention relates~~ to a method for determination of a zero error in a Coriolis gyro.

Description of the Prior Art

Coriolis gyros (also referred to as "vibration gyros") are ~~being used increasingly~~ in increasing use for navigation. They possess ~~Coriolis gyros have~~ a mass system that ~~which~~ is caused to oscillate with the ~~This~~ oscillation ~~is~~ generally being the ~~a~~ superimposition of a large number of individual oscillations.

The ~~These~~ individual oscillations of the mass system are initially independent of one another and can ~~each~~ be referred to abstractly as "resonators". At least two resonators are required for operation of a vibration gyro: one ~~of these resonators~~ (the first resonator) is artificially stimulated to oscillate, and this is referred to below ~~in the following text~~ as the "stimulating oscillation". The other ~~resonator~~ (the

second resonator) is stimulated to oscillate only when the vibration gyro is moved/rotated. This is because Coriolis forces occur in this case that ~~which~~ couple the first resonator to the second resonator, absorb energy from the stimulating oscillation of the first resonator, and transfer it ~~this~~ to the read oscillation of the second resonator. The oscillation of the second resonator is referred to below ~~in the following text~~ as the "read oscillation".

In order to determine movements (in particular rotations) of the Coriolis gyro, the read oscillation is tapped off and a corresponding read signal (e.g. ~~for example~~ the read oscillation tapped-off signal) is investigated to determine whether any changes have occurred in the amplitude of the read oscillation, as they ~~which~~ represent a measure of the rotation of the Coriolis gyro.

Coriolis gyros may be implemented as both open-loop ~~open-looped systems~~ and ~~as~~ closed-loop ~~closed-looped~~ systems. In a closed-loop system, the amplitude of the read oscillation is continuously reset to a fixed value (preferably zero) by ~~via respective~~ control loops.

An ~~One~~ example of a closed-loop version of a Coriolis gyro will be described below in conjunction

with ~~in the following text, with reference to~~ Figure 2, a schematic diagram of a Coriolis gyro in accordance with the prior art ~~in order to illustrate further the method of operation of a Coriolis gyro~~. The ~~A Coriolis~~ gyro 1 includes ~~such as this has~~ a mass system 2 that ~~which~~ can be caused to oscillate and is also referred to below ~~in the following text~~ as a "resonator". (A distinction exists ~~must be drawn~~ between this expression and the abstract "resonators" term previously employed for ~~mentioned above, which represent~~ individual oscillations of the "real" resonator. As ~~already~~ mentioned, the resonator 2 may be considered ~~regarded~~ as a system composed of two "resonators" (a ~~the~~ first resonator 3 and a ~~the~~ second resonator 4)). Each of ~~Both~~ the first and the second resonators ~~resonator~~ 3, 4 is ~~are each~~ coupled to a force sensor (not shown) and to a tapping system (not shown). The noise ~~which is~~ produced by the force sensors and the tapping systems is indicated schematically ~~here~~ by Noise1 (reference symbol 5) and Noise2 (reference symbol 6).

The Coriolis gyro 1 includes ~~furthermore has~~ four control loops. A first control loop controls ~~is used to control~~ the stimulating oscillation (that is to say the frequency of the first resonator 3) at a fixed frequency (resonant frequency). It comprises ~~The first control loop has~~ a first demodulator 7, a first low-

pass filter 8, a frequency regulator 9, a VCO (voltage controlled oscillator) 10 and a first modulator 11.

A second control loop controls ~~is used to control~~ the stimulating oscillation at constant amplitude. It comprises ~~and has~~ a second demodulator 12, a second low-pass filter 13 and an amplitude regulator 14.

~~A~~ Third and ~~a~~ Fourth control loops ~~loop~~ are employed ~~used~~ to reset the ~~those~~ forces that ~~which~~ stimulate the read oscillation. ~~In this case,~~ The third control loop includes ~~has~~ a third demodulator 15, a third low-pass filter 16, a quadrature regulator 17 and a third modulator 22 while the fourth control loop comprises ~~contains~~ a fourth demodulator 19, a fourth low-pass filter 20, a rotation rate regulator 21 and a second modulator 18.

The first resonator 3 is stimulated at ~~its~~ resonant frequency ù1. The resultant stimulating oscillation is tapped off, ~~is~~ phase-demodulated by means of the first demodulator 7, and a demodulated signal component is supplied to the first low-pass filter 8~~,~~ that ~~which~~ removes the sum frequencies. ~~from it.~~ (The tapped-off signal is also referred to below ~~in the following text~~ as the stimulating oscillation tapped-off signal.) An output signal from the first

low-pass filter 8 is applied to a frequency regulator 9 which controls the VCO 10, as a function of the signal supplied to it, such that the in-phase component essentially tends to zero. ~~For this purpose,~~ The VCO 10 passes a signal to the first modulator 11, which ~~itself~~ controls a force sensor such that a stimulating force is applied to the first resonator 3. When ~~If~~ the in-phase component is zero, ~~then~~ the first resonator 3 oscillates at its resonant frequency ù1. (It should be noted ~~mentioned~~ that all of the modulators and demodulators are operated on the basis of ~~this~~ resonant frequency ω1.)

The stimulating oscillation tapped-off signal is also applied ~~supplied~~ to the second control loop and ~~is~~ demodulated by the second demodulator 12. The ouput of the second demodulator 12 ~~whose output~~ is passed to the second low-pass filter 13~~,~~ whose output ~~signal~~ is, in turn, applied ~~supplied~~ to the amplitude regulator 14. The amplitude regulator 14 controls the first modulator 11 in response to ~~as a function of~~ this signal and the output of a nominal amplitude sensor 23 to cause ~~such that~~ the first resonator 3 to oscillate ~~oscillates~~ at a constant amplitude (i.e. ~~that is to say~~ the stimulating oscillation has ~~a~~ constant amplitude).

As ~~has already been~~ mentioned above, Coriolis forces (indicated by the term FC·cos(ω1·t) in Figure 2)

~~the drawing -~~ occur on movement/rotation of the Coriolis gyro 1. They ~~which~~ couple the first resonator 3 to the second resonator 4, and thus cause the second resonator 4 to oscillate. A resultant read oscillation of ~~at the~~ frequency ω2 is tapped off and ~~so that~~ a corresponding read oscillation tapped-off signal (read signal) is supplied to both the third and the fourth control loops. ~~loop.~~ This signal is demodulated in the third control loop by the third demodulator 15, sum frequencies are removed by the third low-pass filter 16, and the low-pass-filtered signal is supplied to the quadrature regulator 17. The ~~whose~~ output of the quadrature regulator 17 ~~signal~~ is applied to the third modulator 22 ~~so as~~ to reset corresponding quadrature components of the read oscillation. Analogously, ~~to this,~~ the read oscillation tapped-off signal is demodulated in the fourth control loop by the fourth demodulator 19, passed ~~passes~~ through the fourth low-pass filter 20, and the ~~a correspondingly~~ low-pass-filtered signal then ~~is~~ applied ~~on the one hand~~ to the rotation rate regulator 21 (whose output ~~signal~~ is proportional to the instantaneous rotation rate and ~~is~~ passed as a rotation rate measurement ~~result~~ to a rotation rate output 24) and ~~on the other hand~~ to the second modulator 18 that ~~which~~ resets corresponding rotation rate components of the read oscillation.

A Coriolis gyro 1 as described above may be

operated in both ~~a~~ double-resonant ~~form~~ and ~~in a~~ non-double-resonant forms ~~form~~. When ~~If the Coriolis gyro 1 is~~ operated in a double-resonant form, ~~then~~ the frequency ω2 of the read oscillation is approximately equal to that ~~the frequency~~ of the stimulating oscillation (ω1). ~~while, in contrast,~~ In the non-double-resonant case, the frequency ω2 of the read oscillation differs ~~is different~~ from ~~the frequency~~ ω1. ~~of the stimulating oscillation.~~ In ~~the case of~~ double resonance, the output signal from the fourth low-pass filter 20 contains corresponding information about the rotation rate. ~~while,~~ In contrast ~~in the~~ (non-double-resonant case), the output signal from the third low-pass filter 16 contains the rotation rate information. In order to switch between the ~~different~~ double-resonant and non-double-resonant operating modes, a doubling switch 25 ~~is provided, which~~ selectively connects the outputs of the third and the fourth low-pass filter 16, 20 to the rotation rate regulator 21 and the quadrature regulator 17.

The mass system 2 (resonator) generally has two or more natural resonances ~~that is to say~~ (i.e. different natural oscillations of the mass system 2 can be stimulated). One of the ~~these~~ natural oscillations is the artificially produced stimulating oscillation. Another ~~A further~~ natural oscillation is represented by the read oscillation, which is stimulated by ~~the~~

Coriolis forces <u>upon</u> ~~during~~ rotation of the Coriolis gyro 1. As a result of ~~the~~ mechanical structure and ~~because of~~ unavoidable manufacturing tolerances, it is impossible to prevent other natural oscillations, in addition to the stimulating oscillation and the read oscillation of the mass system 2, in some cases <u>far removed</u> ~~well away~~ from ~~their~~ resonance, <u>from</u> also being stimulated. <u>Such</u> ~~However, the~~ undesirably stimulated natural oscillations <u>change</u> ~~result in a change in~~ the read oscillation tapped-off signal <u>as they</u> ~~since these natural oscillations~~ are also (at least partially) read with the read oscillation signal tap. The read oscillation tapped-off signal is <u>thus</u> ~~accordingly~~ composed of a part ~~that is~~ caused by Coriolis forces and a part <u>that</u> ~~which~~ originates from the stimulation of undesired resonances. The undesirable part causes a zero error ~~in the Coriolis gyro,~~ <u>of unknown</u> ~~whose~~ magnitude ~~is unknown~~. In <u>such a</u> ~~which~~ case it is not possible to differentiate between <u>the</u> ~~these~~ two parts when the read oscillation ~~tapped-off~~ signal is tapped off.

<u>SUMMARY AND OBJECTS OF THE INVENTION</u>

<u>It is therefore an object of</u> ~~The object on which~~ the invention ~~is based is~~ to provide a method <u>for determining</u> ~~by means of which~~ the influence <u>of</u> ~~as described above of~~ the oscillations of "third" modes ~~can be established~~ and <u>thus</u> the zero error <u>in the</u>

tapped-off read oscillation of a Coriolis gyro. ~~can thus be determined.~~

~~This object is achieved by the method as claimed in the features of patent claim 1. The invention also provides a Coriolis gyro, as claimed in patent claim 7. Advantageous refinements and developments of the idea of the invention are contained in the respective dependent claims.~~

The present invention addresses the above object by providing, in a first aspect, ~~According to the invention, in the case of~~ a method for determination of a zero error of a Coriolis gyro. According to such method, the resonator of the Coriolis gyro has appropriate disturbance forces applied to it such that at least one natural oscillation of the resonator is stimulated. Such natural oscillation ~~which~~ differs from the stimulating oscillation and from the read oscillation of the resonator. ~~in which case~~ A change in a read signal that ~~which~~ represents the read oscillation and results from the stimulation of ~~the~~ at least one natural oscillation is determined as a measure of the zero error.

~~In this case, the expression "resonator" means the entire mass system of the Coriolis gyro that is caused to oscillate, that is to say with reference to~~

~~Figure 2, that part of the Coriolis gyro which is annotated with the reference number 2.~~

~~The disturbance forces are preferably alternating forces at appropriate disturbance frequencies, for example a superimposition of sine and cosine forces. In this case, the disturbance frequencies are advantageously equal to, or essentially equal to, the natural oscillation frequencies of the resonator. The changes in the read signal (disturbance component) can be recorded by subjecting the read signal to a demodulation process based on the disturbance frequencies.~~

~~The zero error contribution which is caused by one of the at least one natural oscillations (that is to say by one of the "third" modes) is preferably determined by determination of the strength of the corresponding change in the read signal. Determination of the corresponding resonance Q factor of the natural oscillation, and by calculation of the determined strength and resonance Q factor.~~

~~The resonance Q factor of a natural oscillation is preferably determined by detuning the corresponding disturbance frequency, while at the same time measuring the change that this produces in the read signal.~~

~~In order to investigate the effects of the undesired natural oscillations on the read oscillation tapped-off signal, two or more of the natural oscillations can be stimulated at the same time, and their "common" influence on the read oscillation tapped-off signal can be recorded. All of the disturbance natural oscillations of interest are, however, preferably stimulated individually, and their respective effect on the read oscillation tapped-off signal is observed separately. The zero error contributions obtained in this way from the individual natural oscillations can then be added in order to establish the "overall zero error" (referred to here as the "zero error") produced by the natural oscillations.~~

~~The disturbance component can be determined directly from the read oscillation tapped-off signal.]~~

In a second aspect, the invention ~~also~~ provides a Coriolis gyro ~~which is~~ characterized by a device for determination of a zero error. ~~of the Coriolis gyro.~~ Such ~~The~~ device includes ~~has:~~ a disturbance unit. The unit ~~which~~ applies appropriate disturbance forces to the resonator of the Coriolis gyro so ~~such~~ that at least one natural oscillation of the resonator is stimulated that ~~which~~ differs from the stimulating oscillation and the read oscillation of the resonator. ~~and~~

A disturbance signal detection unit is also provided. Such unit ~~which~~ determines a disturbance component as a measure of the zero error. The disturbance component ~~which~~ is contained in a read signal that represents the read oscillation ~~and has been~~ produced by the stimulation of ~~the~~ at least one natural oscillation.

The foregoing and other features of the invention will become further apparent from the detailed description that follows. Such description is accompanied by a set of drawing figures in which numerals, corresponding to those of the written description, point to the features of the invention. Like numerals refer to like features throughout both the written description and the drawing figures.

~~The invention will be described in more detail in the form of an exemplary embodiment in the following text, with reference to the accompanying figures in which:~~

BRIEF DESCRIPTION OF THE DRAWINGS

Figure 1 is a ~~shows the~~ schematic diagram ~~design~~ of a Coriolis gyro in accordance with ~~which is based on the method according to~~ the present invention; and

Figure 2 is a schematic block diagram of a

~~shows the schematic design of a conventional~~ Coriolis gyro in accordance with the prior art.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENT

Figure 1 is a schematic diagram of a Coriolis gyro in accordance with the present invention. In it, parts and devices which correspond to those of the prior art devices of ~~from~~ Figure 2 are indicated by identical ~~annotated with the same~~ reference symbols ~~in the drawings,~~ and ~~will~~ not discussed below. ~~be explained again.~~ The method of ~~according to~~ the invention will be explained below with reference to the ~~in more detail using an exemplary embodiment in the following description with reference to~~ Figure 1.

A reset Coriolis gyro includes a ~~is additionally provided with a~~ control and evaluation unit 26, a modulator 27 (disturbance unit) having ~~with~~ a variable frequency ωmod and, ~~a~~ preferably, an adjustable amplitude, ~~two~~ demodulators 28, 29 that ~~which~~ operate in quadrature at the frequency ωmod, and ~~a~~ fifth and ~~a~~ sixth low-pass filters ~~filter~~ 30 and 31. The disturbance unit 27 produces an alternating signal at the frequency ωmod. This ~~which~~ is added to the force input of the stimulating oscillation (first resonator 3). The ~~Furthermore, This~~ signal is also supplied as a reference signal to the demodulators 28, 29. An alternating force, corresponding ~~which~~

~~corresponds~~ to the alternating signal, is thus additionally applied to the resonator 2. Such ~~This~~ alternating force stimulates a further natural oscillation (also referred to as a "third" natural mode) of the resonator 2 (in addition to the stimulating oscillation). The ~~whose~~ effects of the further natural oscillation can be observed in the form of a disturbance component in the read oscillation tapped-off signal.

~~If the disturbance forces are produced by alternating forces at specific disturbance frequencies, the disturbance signal detection unit has a demodulation unit by means of which the read signal is subjected to a demodulation process (synchronous demodulation at the disturbance frequencies). The disturbance component is determined from the read signal in this way.~~

~~The disturbance signal detection unit preferably has two demodulators which operate in quadrature with respect to one another, two low-pass filters and a control and evaluation unit, with the demodulators being supplied with the read oscillation tapped-off signal, with the output signals from the two demodulators being filtered by in each case one of the low-pass filters, and with the output signals from the low-pass filters being supplied to the control and~~

~~evaluation unit, which determines the zero error on this basis.~~

~~The control and evaluation unit acts on the disturbance unit on the basis of the signals supplied to it, by which means the frequencies of the disturbance forces can be controlled by the control and evaluation unit.~~

~~In this example,~~ The read oscillation tapped-off signal is subjected to a demodulation process in phase and ~~in~~ quadrature with respect to the stimulation produced by the modulator 27. <u>Such demodulation</u> ~~which~~ process is <u>performed</u> ~~carried out~~ by the demodulators 28, 29 at ~~the~~ frequency ωmod (disturbance frequency). The signal <u>thus</u> obtained ~~in this way~~ is low-pass filtered (by the fifth and the sixth low-pass filters 30, 31), and ~~is~~ supplied to the control and evaluation unit 26.

<u>The</u> ~~This~~ control and evaluation unit 26 controls the frequency ωmod and, if appropriate, the stimulation amplitude of the alternating signal ~~that is~~ produced by the modulator 27, in such a way that the frequencies and strengths of the "significant" third natural modes, as well as their Q factors, are continuously determined. <u>Such factors are utilized by</u> the control and evaluation unit 26 ~~uses this~~ to calculate ~~the~~ respective instantaneous bias error.

Such calculated errors are supplied to correct ~~and supplies it for correction of the~~ gyro bias.

The idea on which the invention is based is to artificially stimulate undesired natural oscillations of the resonator (that is to say natural oscillations which are neither the stimulating oscillation nor the read oscillation) and to observe their effects on the read oscillation tapped off signal. The undesired natural oscillations are, in such ~~this~~ case, stimulated by application of appropriate disturbance forces to the resonator. The "penetration strength" of such disturbances to the read oscillation tapped-off signal represents a measure of the zero error (bias) of the Coriolis gyro. Thus, if the strength of a disturbance component contained in the read oscillation tapped-off signal is determined and is compared with the strength of the disturbance forces producing this disturbance component, it is then possible to derive the zero error. ~~from this.~~

The artificial stimulation of the natural oscillations and the determination of the "penetration" of the natural oscillations to the read oscillation tapped-off signal preferably takes place during operation of the Coriolis gyro. However, the zero error can also be established without the existence of any stimulating oscillation.

Both the strength of the disturbance component in the read signal and the resonance Q factor of the corresponding natural oscillation must be determined in order to determine the zero error. These values are then calculated ~~in order~~ to obtain the zero error. ~~In order~~ To determine the resonance Q factor, the frequency of the disturbance unit must be detuned over the resonance while, at the same time, carrying out a measurement by means of the disturbance signal detector unit. This is preferably achieved by means of software, whose function is as follows:

- searching for the "significant" third (disturbing) natural resonances
- moving away from the associated resonance curve
- calculating ~~calculation of~~ the Q factor and the strength of the stimulation, and the "visibility" of this third oscillation in the read channel; and
- calculating ~~calculation of~~ the contribution of this third oscillation to the bias on the basis of the Q factor, strength and "visibility".

The bias can be compensated ~~for~~ by calculation (e.g., by means of ~~the~~ software).

While this invention has been described with reference to its presently-preferred embodiment, it is not limited thereto. Rather, the invention is limited only insofar as it is defined by the following set of patent claims and includes within its scope all equivalents thereof.

What is claimed is: ~~Patent claims~~

1. A method for determination of a zero error in a Coriolis gyro (1′) in which

- the resonator (2) of the Coriolis gyro (1′) has appropriate disturbance forces applied to it such that at least one natural oscillation of the resonator (2) is stimulated, which differs from the stimulating oscillation and from the read oscillation of the resonator (2), and
- a change in a read signal which represents the read oscillation and results from the stimulation of the at least one natural oscillation is determined as a measure of the zero error.

2. The method as claimed in claim 1, characterized in that the disturbance forces are alternating forces at appropriate disturbance frequencies, with the disturbance frequencies being natural oscillation frequencies of the resonator (2).

3. The method as claimed in claim 2, characterized in that the change in the read signal is recorded by subjecting the read signal to a demodulation process based on the disturbance frequencies.

4. The method as claimed in one of claims 1 to 3, characterized in that the zero error contribution which is produced by one of the at least one natural oscillations is determined by determination of the strength of the corresponding change in the read signal, determination of the corresponding resonance Q-factor of the natural oscillation and by calculation of the determined strength and resonance Q-factor.

5. The method as claimed in claim 4, characterized in that the resonance Q-factor of a natural oscillation is determined by detuning the corresponding disturbance frequency while at the same measuring the change produced by this in the read signal.

6. The method as claimed in one of the preceding claims, characterized in that two or more successive natural oscillations of the resonator (2) are stimulated, corresponding changes in the read signal are recorded, and corresponding zero error contributions are determined, with the zero error of the Coriolis gyro (1') being determined by addition of the zero error contributions.

7. A Coriolis gyro (1′) characterized by a device for determination of the zero error of the Coriolis gyro (1′) having:

- a disturbance unit (27) which applies appropriate disturbance forces to the resonator (2) of the Coriolis gyro (1′) such that at least one natural oscillation of the resonator (2) is stimulated, which differs from the stimulating oscillation and the read oscillation of the resonator (2), and
- a disturbance signal detection unit (26, 28, 29, 30, 31), which determines a disturbance component, which is contained in a read signal that represents the read oscillation and has been produced by the stimulation of the at least one natural oscillation, as a measure of the zero error.

8. The Coriolis gyro (1') as claimed in claim 7, characterized in that the disturbance signal detection unit comprises two demodulators (28, 29), which operate in quadrature with respect to one another, two low-pass filters (30, 31) and a control and evaluation unit (26), with the demodulators (28, 29) being supplied with the read oscillation tapped-off signal, with the output signals from the two demodulators (28, 29) being filtered by in each case one of the low-pass filters (30, 31), and with the output signals from the low-pass filters (30, 31) being supplied to the control and evaluation unit (26), which determines the zero error on this basis.

9. The Coriolis gyro (1') as claimed in claim 8, characterized in that the control and evaluation unit (26) acts on the disturbance unit on the basis of the signals supplied to it, by which means the frequencies of the disturbance forces can be controlled by the control and evaluation unit (26).

ABSTRACT

~~Method for determination of a zero error in a Coriolis gyro~~

~~In~~ A method for determination of the zero error of a Coriolis gyro. ~~(1')~~ Appropriate disturbance forces are applied to the resonator ~~(2)~~ of the Coriolis gyro ~~(1') has it~~ such that at least one natural oscillation of the resonator ~~(2)~~ is stimulated that ~~which~~ differs from the stimulating ~~oscillation~~ and ~~from the~~ read oscillations. ~~oscillation of the resonator (2), and~~ A change in a read signal which represents the read oscillation and results from the stimulation of the at least one natural oscillation is determined as a measure of the zero error.

~~(Figure 1)~~